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USE OF CLOUD PICTURES IN CYCLOGENESIS FORECASTING

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16. Abstract

The authors conclude from satellite photographs that cyclones can be predicted from cloud formations. Such formations are analyzed along with a "tropical type" of cyclone.

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USE OF CLOUD PICTURES IN CYCLOGENESIS FORECASTING

Dr. R. Zhalyu and T. P. Popova[1]

A conclusion is drawn from satellite cloud pictures that an initial phase in the development of a cyclone is related to certain cloud formations. Typical cloud situations in the initial stage of cyclogenesis are considered and a cyclone of the "tropical kind" over the Atlantic Ocean near the European Coast is analyzed. /14*

Up to the present time the study of the cyclogenesis process and determination of the moment of cyclone formation has been an urgent and extremely difficult task for meteorology. Examination of satellite pictures of cloud cover leads to the idea that cyclogenesis is first revealed in cloud evolution. Being the product of the upward movement of air, the cloud picture reflects these vertical movements which in a given case accompany the development of a cyclone.

The connection of cloud formation with vertical movement is well documented in World literature. Three basic groups of clouds are differentiated: clouds caused by the movement of the air directed upward (Ci, Cs, As, Ns), convective clouds (Cu, Cb) and turbulent motion clouds (St, Sc, Ac, Cc). From the point of view of cyclogenesis the two first groups of clouds engender the greatest interest.

Comparison of estimates of vertical motion velocity with data on cloud formation from a satellite [5] shows that, independent of shape, a small number of clouds (less than 50% of the covered Earth surface) is accompanied by descending movements; compact cloud cover in a stratified form is joined with upward movement clouds; a large amount of cumulus formation occurs in conditions favorable for convective motion, but near zero in respect to the velocity of directed motion.

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This relationship between vertical movement and clouds satisfies the dispersion of both in cyclones. A cyclone, in its origin and development, goes through definite stages. In the first stage the upward motion includes almost all the area of the cyclone. With the development of the cyclone the focal point of upward activity becomes mixed with the first part of the cyclone, and behind it is found a focus of descending movement which is gradually dispersed throughout the cyclonic area [6]. After this cyclone evolution ceases.

The cloud system of the cyclone follows this course of life along with the cyclone. A cloud vortex, which is formed as early as the second step in the cyclone life [4, 7], is common in all developing cyclones. At the beginning of this stage, as satellite pictures show, the cloud cover of every cyclone is distinguished by its own individual properties. This individuality is coupled with the nature of the vertical motion accompanying the cyclogenesis.

Five basic cloud cover structures are distinguished, characterized by the initial stage of cyclogenesis [12]. /15

1. Wave deflection of the frontal cloud zone and the appearance of anticyclonic bands of cirrus clouds. It is a well-known fact that the wave deflection of the frontal cloud band corresponds to the formation of wave turbulence at the front. But not all wave turbulence evolves into cyclones. The turbulent activity depends on the intensity of the advective thermal vapor in the area of the wave. The appearance of a cirrus cloud cover demonstrates great wave turbulence activity. Cirrus clouds result from the intensive advective warm air in the upper-half of the troposphere in the vicinity of the wave.

Figure 1 (14 October 1971) gives an example of the cloud activity of a frontal wave over Eastern Europe as seen on a photograph taken in space. Plotted on the cloud cover diagram are the isolines for thermal advection at °C/12 hours at a height of 500 mb and the vertical velocity in cm/sec at heights of 850, 700 and 500 mb at probe points, distributed according to wind data. The method of computing the vertical velocity by using wind probe data permits consideration of vertical motion occasioned by baroclinity [2]. In a given case the large vertical velocity values indicate priority of the baroclinity factor in the evolution of cyclones from frontal waves.

2. The "Cap" of cirrus clouds with an anticyclonic deflection of the northern edge. In general this situation originates in the area of large horizontal temperature gradients [9]. But in this case the photographs do not always sharply denote an expressed frontal cloud zone. The cloud "Caps" appears as if isolated from other clouds. It forms in an area of intensive heat advection. An example of a "Cap" above the Balkans is given in Figure 1 (9 January 1967). The thermal advective field (°C/12 hours) at a height of 700 mb is represented by isolines. The cyclone appearing beneath the cloud cap is the result of a local drop in pressure in the area of intensive hot air advection. Later on a frontal baroclinity effect plays a fundamental role in the development of the cyclone and its movement to the Black Sea.

3. A "Cap" of cirrus clouds at the leading edge of a bank of cumulus clouds of a second cold front. Active intrusion of cold air behind a cyclone from the north causes a reciprocal draft of warm air from the south and produces active, advective thermal vapor in the secondary front zone. Examples of these cloud situations are given in Figure 1 (21 April 1969 and 21-22 March 1970).

The cloud formation of 21 April 1969 evolved above Eastern Europe behind a cyclone. The thermal advection values at the probe points in the cloud "Cap" at heights of 850, 700 and 500 mb, plotted on the chart, were calculated from wind data. Attention should be called to two moments. Cold advection is observed in the back part of the cloud "Cap", where clouds of cumulus formation predominate. Warm advection is observed in the front part of the "Cap", where the screen of cirrus clouds is located. The second moment is acceleration of the cold advection with height. This guarantees the formation of an unstable air stratification and sets up the conditions for an intensive evolution of convective cloud cover. Here we actually observe mighty cumulus rain clouds and cloud bursts occur. Within 24 hours the developing cyclone has already acquired an occluded structure and its cloud system presents a sharply expressed cloud vortex.

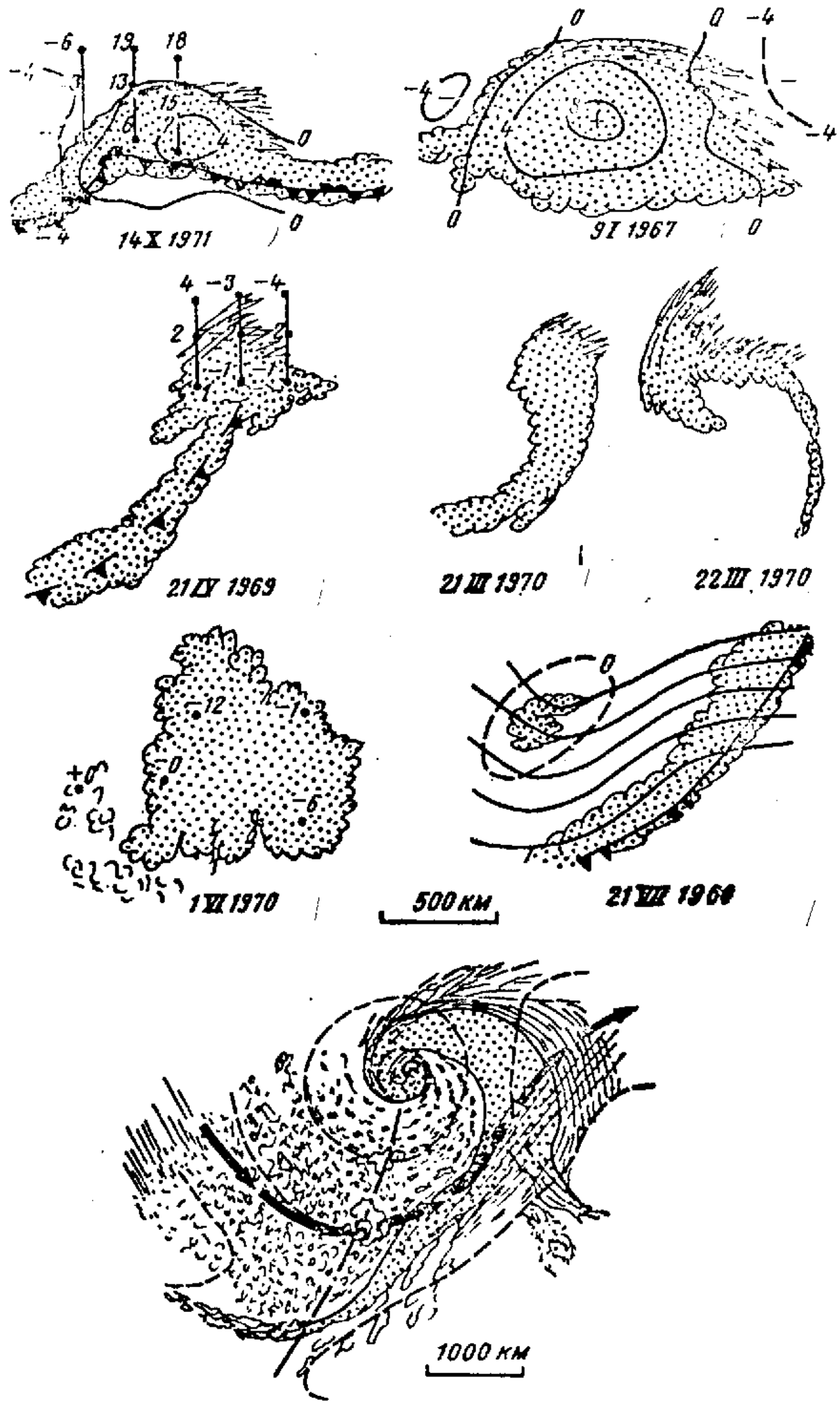

Figure 1. Diagrams of Typical Cloud Situations in the Initial Stage of Cyclogenesis.

G. Monceau and S. Pastre observed a similar case (21-22 March 1970) above the Atlantic [11]. Just as in the first case, a frontal cloud zone with a "Cap" at its end predominated in the rear trough of an extensive cyclone over the /17 North Atlantic. Data from probing indicated the existence of a "drop" of cold air behind the front. Just as in the previous case, the bands of cirrus clouds were not clearly connected with the circulation in the vortical half of the troposphere and were in all probability the result of warm advection at these heights. Dynamic factors of a synoptic scale and, particularly, calculated, directed, vertical velocities were insignificant. Just as in the first case, the cyclogenetic process was not active and the cloud system quickly brought about a vortical structure, first in the shape of a "hammer" (Figure 1, 22 March), and later in the shape of a regular cyclonic vortex.

4. A solid mass of evolving cumulus clouds against a background of a comparatively small number of clouds. This kind of situation develops in the presence of a local area of intensive convection where the convection is maintained by the instability of the air, caused by thermal advection. The vertical profile of the thermal advection is such that the advection supports a superadiabatic gradient for a lengthy period of time. Resolution of the instability occurs by way of intensive convection.

An example of such a situation over Asia Minor is given in Figure 1 (1 June 1970). The vertical gradient of thermal advection in a layer of 850-500 mb is plotted at probe points. This gradient is negative in areas occupied by the mass of powerful cumulus clouds, and positive outside of it.

In the region occupied by the powerful cumulus cloud cover was born a cyclone which developed and moved out over the Black Sea. Further evolution of the cyclone was supported by the baroclinity effect in the cyclone area penetrated by a cold front from the Balkans.

5. A secondary cloud vortex in the lower cyclone system. A cloud vortex of cumulus shaped clouds developing behind the evolved cyclone may serve as a sign of either wave formation on a cold front or the origin of a new cyclonic perturbation. Such a vortex is commonly formed below a high cold trough or below an isolated cold center in a local area of a positive velocity vortex.

Convergence in the lower levels and cold advection above promote the creation of instability and the stormy evolution of convective clouds. The clouds are grouped together either in a "heap" of unclear structure or in "commas" representing the first stage in the organization of a cloud vortex. Afterward these formations are converted into a "secondary" cloud vortex related to the already started process of cyclogenesis.

Examples of secondary cloud vortices are given in Figure 1 for the situation of 21 July 1966 above Western Siberia and by the generalized diagram above the North Atlantic. The solid line for the 21 July situation shows the contours OT $_{1000}^{500}$, and the pointed line shows the zero isoline computed from the velocity vortex values in the stratum near the ground. The "plus" sign indicates the center of the area of positive velocity vortex. A cyclone developed on the cold front within 24 hours after observation of the secondary cloud vortex [8].

For the situation above the North Atlantic (bottom of chart) the positions for the cold trough axis (dotted line with dashes), of the jet stream axis (heavy arrows) and of the surface contours at 500 mb (dotted line) are identified. This diagram also illustrates cyclogenesis on the cold front penetrating the subtropical latitudes of the Atlantic and eroding in the lower layers. The increase in the barometric gradients brings about an intensive draft of tropical air toward the north and the formation of a bank of stratified clouds.

The five typical situations presented here are the precursors of cloud systems in the overwhelming majority of cyclones evolving in the temperate /18
latitudes. The final stage in the evolution of the cloud systems of all cyclones is the cloud vortex.

The classical diagram of the evolution of the cloud system of cyclones in the temperate latitudes is given in [13]. But this process proceeds in an individual manner for each cyclone. Most often this concerns the velocities with which the evolution of the cloud system develops. Study of the cloud cover of cyclones on photographs from satellites permit the conclusion to be reached that in some cases even 12 hour intervals proved to be too great to detect all stages of development of a cyclonic cloud system.

To a significant degree this refers to cyclones of the so-called "tropical kind" which develop over the Atlantic along the coast of Europe. The development of this type of cyclone takes place with an active incursion of air of tropical origin into the temporal latitudes of the Atlantic above a "film" of earlier frigid air.

The development of a cyclone proceeds very violently and rapidly (less than one 24-hour day). Barometric tendencies in both directions reached 12 mb after 3 hours and more. A barogram has the shape of the letter V. Winds at the surface of the Earth reach scores of kilometers per hour. The arrival of a cyclone is accompanied by heavy downpours and thunderstorms.

Until the appearance of satellites these cyclones were a great enigma for meteorologists, because of the scanty network of meteorological stations on the Atlantic, and forecasting their development presented great difficulties. With the advent of films of cloud cover some properties of these "tropical cyclones" on the European shores have been explained and analyzed. The basic difference between them and regular temperate latitude cyclones is found in the violent development of their cloud systems and in the rapidity of the cyclogenetic process. The forming cloud vortex is usually circular and has a diameter of less than 1,000 km.

In accord with the classification given above, it would be possible to refer the initial stage in the development of such a "tropical" cyclone to the third manner. However, in this case the process occurs on a grand scale. This can be illustrated with the analysis of satellite pictures received during the time of the hurricane of 13 February 1972 over France [10].

The first phase was the initial conditions.

Three peculiarities in the formation of cloud cover over the North Atlantic, characterizing the initial conditions for the birth of a cyclone, were observed with the aid of a satellite photograph of 12 February (photograph 5).

The first peculiarity was a mass of stratified Ac-As clouds in the shape of a heterogeneous cloud bank about 200 km long extending from the southwest toward the northeast. It was about 100 km wide in the southwest and about 500 km wide in the northeast. These clouds exhibited "trails" of propagation of warm air of tropical origin in the middle layers of the troposphere. The formation of this dense layered mass of clouds was related to the fact that usually in this situation we find in the north cold air with an incursion of very moist warm air rising toward the cold air, which leads to the formation of the dense stratified cloud mass which we see on the satellite photograph picture.

The second peculiarity was the "cirrus ribbon" hanging above the mass of layered clouds. This ribbon was wider than the prevalent mass of layered cloud below it. The northern edge of this ribbon of cirrus clouds was sharply circumscribed. This stringy "cirrus" ribbon extended toward the northeast, where it adopted a small, but clearly expressed, anticyclonic curvature, and then abruptly came to an end. Both the Ac-As and Ci cloud systems have a sort of "club". The "cirrus ribbon" exhibits "tracks" of tropical air advection in the upper troposphere. This is related to the jet stream and is located beneath the tropical tropopause on the warm southern side of the jet stream. The northern /19
boundary of the "cirrus ribbon" coincides with the axis of the jet stream. In the northern part of the jet stream at the junction with the Arctic tropopause there are no clouds in the upper troposphere.

The third peculiarity of the cloud cover, immediately to the southwest from the very wide and the dense part of the Ac-As and Ci cloud mass — are located small spiral and curving Cu banks, evidence of weak cyclonic circulation in lower layers. These lower clouds are called "stakes", indicating the area occupied by the mass of cold air of Arctic origin. They cover an extensive geographic zone behind the fundamental cold front and form a rear cloud layer. Small circular heaps of clouds, separately discernable on satellite photographs, indicate the existence of medium-sized low pressure areas.

The second phase is the cyclogenesis phase.

Cyclogenesis is produced by two combined and simultaneously acting effects: new advection of fresh frigid air from the north and intensive advection of tropical air from the south. This situation is caused under conditions of a subtropical surface anticyclonic field when, at heights at a level of 500 mb, there is reinforcement of the warm barometric peak which causes an increase in air velocity in the jet stream [1]. In the middle layers of the troposphere contact between air masses of sharply differing temperatures causes a significant increase in the horizontal thermal gradient. In the case in question of 13 February at 00 hours Greenwich Mean Time at a level of 700 mb on the twentieth west longitude meridian the difference in temperature between 43 and 50° north latitude amounted to 16°C, i.e., about 2°C per 100 km. As the result of the cyclonic circulation fresh Arctic air came to the southwest under the mass of layered clouds and approached the warm air. The process of cyclogenesis began. On satellite photographs the process of cyclogenesis appears in the formation of a "cloud cap" or "hammer" from the Ac-As and Ci cloud masses.

The third phase is the "extratropical" cyclone.

It is characterized by an intensification of the convergence of the stream in the lower and middle troposphere and of the divergence in the upper troposphere. The intrusion of the cold air intensifies the cyclonic circulation in the lower levels and stimulates the warm moist air in the middle layers to rise. Precipitation is intensified. One of the signs of intensive precipitation is the beginning of stringy Ci cover before and along the sides of the St clouds. However, these cirrus clouds must not be confused with the cirrus band of the jet stream, visible on the photograph of 12 February.

Up to this time the process of cyclogenesis has proceeded in the usual way when two "directed" air masses take part in cyclogenesis, masses which are very different in temperature and moisture content. There was no justification for identifying this given cyclone with tropical cyclones, which have a "hot center".

However, the advection of the tropical air in high areas continues, and the jet stream becomes stronger (velocities reach 130 km/hour). At this moment the axis of the jet stream passes to the north of the depression of the lower layers (Figure 2). The Ac-As cloud system is located under the jet stream. The focal points of rising vertical velocity in the lower half of the troposphere (at levels of 800 and 600 mb) coincide with the depression and lie south of the jet stream axis. Because of the great spread of air at the top, where the circulation is anticyclonic, the cyclone taking shape in the lower levels is still visible at a level of 700 mb, but at 500 mb is expressed only by a barometric trough and disappears completely at a level of 300 mb and above. The fact is that this phenomenon identifies the development of a given cyclone with the depression process of tropical cyclones as long as there is cyclonic circulation in the general development of temperate latitude cyclones and relative coldness /20 is traced higher than levels of 500 mb.

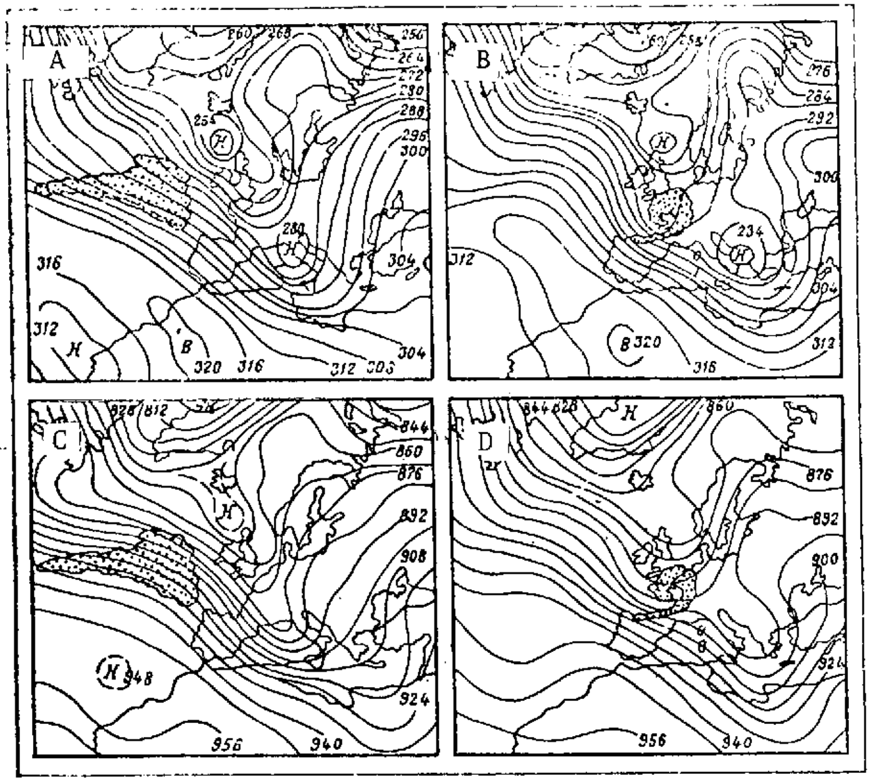

Figure 2. Maps AT_{700} (a, b) and AT_{300} (c, d) 12 (a, b) and 13 (c, d) February 1972.

At the "spreading height" there is an intensive "hurling away" of air which intensifies its "suction" into the cyclone from below, which is accompanied by an active rise of air in the "cyclonic cylinder". Thanks to the development of rotational motion in the lower layers an energetic equilibrium is created. Within the wind field there arises an air vortex in which heat and cold air are mixed. A cloud vortex is formed in the cloud field (photograph 5).

But the life of this cyclone is not long, not longer than 24 hours. Above the continent the cyclone dies quickly. In the middle layers the intensive cyclonic circulation intercepts warm air which feeds the cyclone. Advection of tropical air in the region of the cyclone is cut short. The jet stream switches to the south of the cyclone. Cyclonic circulation begins to die out.

The following properties of the cloud field are characteristic of the "tropical type" of cyclone:

- isolation of the cyclonic system;
- relative limitation of the dimensions of the system (not more than 1,000 km);
- a cloud vortex of a rounded shape with a Ci cap;
- a spiral cloud ribbon most intensely developed in the warm part of the cyclone (in contradistinction to a tropical cyclone, two symmetrical cloud bands are not observed in this cyclone);
- profuse precipitation, mostly north of the cyclone path;
- the wind, the velocity of which attains hurricane force; /21
- a V-shaped barograph.

A few data about the parameters of the atmosphere for the cyclone of 13 February 1972 can be given as supplementary information.

The vertical velocities, calculated with a five-layer model for a dry adiabatic atmosphere with a 150-200 km grid interval, are presented in Table 1. Here we also show the coordinates of the focal points in the lower-half of the troposphere. It follows from the data of Table 1 that the difference between the absolute velocity value in the negative and positive focuses in the cyclone accelerated with height and time. This refers to the activation of the cyclogenesis process. The rise of the air led to the origin of the temperature inversion connected with the extensive tropical air at the top, and also braced the entire thickness of the changing stratum, where the equipotential temperature amounted to 5-15°C. In turn this layer is defined by radial probe data at point K (weather ship); as an example, it was spread over Brest and Trappes at a height of 7 km.

One property must be mentioned in the location of the vertical velocity focal points with reference to the axis of the jet stream. In the initial phase of cyclogenesis the axis of the jet stream passed to the north of the focal points of the rising air (negative vertical velocities), and in the final stage, *vice versa*, to the south of them at the time when the positive focal points (descending air), joined with the cyclone, were continually below the axis of the jet stream. If this property is characteristic of all cyclones of this type, this would be an additional element in cyclogenesis forecasting.

TABLE 1. POSITION AND INTENSIVENESS OF VERTICAL VELOCITY FOCAL POINTS AT mb/3 HOURS

Date, Time	Vertical Velocity Value and Focal Point Center Coordinates			
	800 mb		600 mb	
	Positive	Negative	Positive	Negative
12 February, 12 hours	Not determined	-15 46° n., 22° w.	Not determined	-15 47° n., 24° w.
13 February, 00 hours	+35 46° n., 15° w.	-35 46° n., 8° w.	+65 46° n., 16° w.	-70 47° n., 8° w.
13 February, 12 hours	+25 44° n., 8° w.	-35 47° n., 3° e.	+35 45° n., 7° e.	-55 47° n., 4° e.

Pressure fluctuations at the surface of the Earth. A drop in pressure began at 22 hours on 12 February to the west of the Brittany Penisula. The center of the cyclone passed across Brittany at ten o'clock on 13 February. In 12 hours the pressure dropped to 30 mb. A subsequent rise in pressure by this same amount took place in 7 hours. A positive tendency in pressure modification in the 3 hours from nine to twelve o'clock amounted to 18.2 mb.

Weather. The weather field on the surface of the Earth had a clearly expressed "circular circulating" structure. Maximum velocities of wind reached values of 120-140 km/hours at many points along the cyclone path, beginning in the Province of Brittany and extending to the regions of Touraine and Limousin. The very highest velocity was recorded in Quimper, 170 km/hours. The strongest squalls were observed south of the path of the center of the cyclone. They were observed against a background of strong wind which blew everywhere for several hours with a velocity of about 80 km/hours.

On a vertical cross-section (Figure 3), taken from north to south through the cyclone at noon on 13 February, can be observed an interesting peculiarity /22 in the location of the tropopause on the warm side of the cyclone. The extension of the warm air layers was so impressive that the tropical tropopause was in the shape of a "fold" surrounding the nucleus of strong winds from the jet stream. Periodic contact of the tropopause with this "fold" assured penetration of stratispheric air into the troposphere. This phenomenon proceeds in jerks (jolts) and is accompanied by a certain amount of downward motion producing a "catabatic" wind (ageostrophic), which is directed perpendicularly into a tall stream. This also led to squall-like intensification of wind on the surface of the Earth.

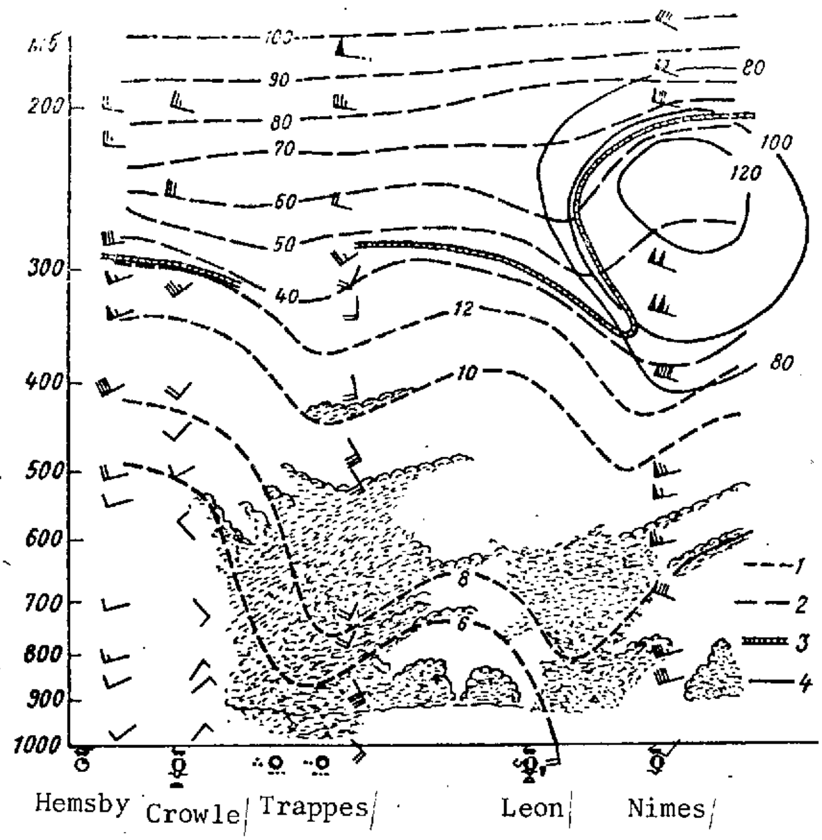

Figure 3. 1, Isolines of pseudopotential temperature; 2, Isolines of potential temperature; 3, Tropopause; 4, Isotachs.

Cloud cover. At the mature phase of the cloud system the angle of opening of the logarithmic spiral was small (about 15°). The cloud system had an almost round form, without any general lengthening of the main spiral band. The spiral band had a width from 100 to 200 km. The "clear spiral" was not quite sharp and "clean", although in the valley of the Rhone River complete clearing was observed. The back portion with the opened cloud cells was impelled forward over the Bay of Biscay to Southwest France. Cumulus clouds appeared in the region of the cold air irruption. The densest cloud cover was seen north of the cloud vortex, where very heavy precipitation occurred.

Precipitation. Some amount of precipitation was connected with the differing rising masses in the cloud sectors. In Poitiers, for example, a warm incursion accompanied by stratified clouds and by a rise in temperature at the surface of the Earth by 4°C during the night produced 9 mm of precipitation by /23
the end of the night. After a 45 minute interruption the rain resumed. But it was already connected with the cold front. 13 mm of precipitation fell and the temperature in the morning dropped by 6°C. These temperature fluctuations were contrary to the general daily trend and characteristic of air masses, differing in thermal properties, passing through a point of observation.

In conclusion it should be said that the hurricane of 13 February 1972 was a relatively unusual phenomenon. About 10 cases of such cyclones have been observed over the Eastern Atlantic and the western part of the Meditteranean Sea in three years. The evolution and configuration of the cloud system, the amplitude of fluctuation in the basic meteorological parameters during the passage of this cyclone, all of this brings this "hurricane" close to a tropical cyclone. A detailed analysis of satellite photographs of the cloud cover in these cases may provide valuable supplementary information about the dynamic parameters of the atmosphere in the practical forecasting of similar events.

Conclusion

In connection with the complexity and great variety of cloud situations in analyzing photographs, the importance of visual information should not be neglected. On the contrary, it should be inspected in all details and aspects of meteorological interpretation, so as not to confuse initial signs, identical at first glance, of phenomena differing in their development.

From a general synoptic point of view, the variety in cloud situations is not really so great, and to a large degree they possess general indicators. However, at the same time they possess a great deal of variation in their constituent elements. It is important to distinguish and separate from the general process strictly local phenomena which have no essential effect upon the process.

Such a detailed visual analysis of cloud formations, from the point of view of different standards, significantly promotes improvement in the general analysis of the synoptic process and its details, as has been shown in the case of the "extra-tropical cyclone".

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